The International Atomic Energy Agency and its Gaseous Waste Management Handbook activity.

Authors: R. Doig, R. Burcl, V. Isupov, Y. Panteleev and J. L. Kovach Abstract:

The IAEA Nuclear Fuel Cycle and Waste Technology is preparing a document "Retention, conditioning and storage of gaseous radionuclides from nuclear fuel cycle facilities". It is expected that the document will be issued in 2001. The plans are to have it available in both CD form and in a hard copy. The document is aimed at those technical and regulatory people who while familiar with general nuclear technology need a "primer" on the application of specific technologies for the air and gas treatment systems involved in the nuclear fuel cycle starting with nuclear fuel fabrication and ending up with waste processing. A team of technical folks from member countries have reviewed and contributed to the document along its three years of preparation. There were three consultants meetings in Vienna preparing drafts of the document. At the present time all sections of the document are prepared in a draft form and the difficult editorial task is the ongoing activity.

The Table of Contents of the document indicates the areas of activity discussed in the document.

#### Contents

- 1.0 Introduction.
- 1.1 Background
- 1.2 Objective
- 1.3 Scope
- 2.0 Physical and Chemical Processes of the Gaseous and Airborne Waste Management Technology.
- 2.1 Introduction
- 2.2 Aerosols
- 2.2.1 Introduction
- 2.2.2 Filtration Theory
- 2.2.2.1 Aerosol Diffusion
- 2.2.2.2 Aerosol Interception
- 2.2.2.3 Aerosol Inertia Capture
- 2.2.2.4 Electrical Forces
- 2.2.3 Filtration Efficiencies
- 2.2.4 Filter Loading
- 2.2.5 Filtration Systems
- 2.2.6 Characteristics of Aerosols
- 2.3.6.1 Aerosols in Nuclear Power Plants
- 2.3.6.2 Aerosols in fuel Fabrication plants
- 2.3.6.3 Aerosols in Reprocessing Plants
- 2.3.6.4 Aerosols in Waste Processing Plants
- 2.2.7 References
- 2.3 Radioiodine (short lived) in NPP's
- 2.3.1 Introduction
- 2.3.2 Radioiodine Forms
- 2.3.3 Airborne Iodine Concentrations
- 2.3.4 Radioiodine Removal Mechanisms
- 2.3.5 Formulas used in Expressing
- radioiodine Removal
- 2.3.6 References
- 2.4 Iodine (long lived) from Reprocessing
- 2.4.1 Introduction
- 2.4.2 Characteristics and arisings of 129I

- 2.4.2.1 Properties of 129I
- 2.4.2.2 Radiological Impact
- 2.4.2.3 Occurrence
- \* In nature
- \* As a result of Nuclear Explosions
- \* As a result of Nuclear Reprocessing
- 2.4.3 Monitoring 129I
- 2.4.3.1 Requirements
- 2.4.3.2 General Survey of Measuring Methods for 129I
- 2.4.3.3 Analysis of 129I
- \* Analysis in Off-gas
- \* Analysis in Solution
- \* Analysis in Environmental Samples
- 2.4.4 Treatment and Conditioning of 129I in Nuclear Fuel

# Reprocessing

- 2.4.4.1 Synopsis and Note on Chemical Forms
- \* Iodine Behaviour During Dissolving of Spent Nuclear Fuel
- \* 129I Desorption into the Gas Phase
- \* Iodine Distributing to Production lines within Spent Fuel

# Reprocessing

2.4.4.2 Processes for Removal of Iodine from Gas

# Streams

- \* Liquid Scrubbing
- \* Caustic and Other Alkaline Scrubbing
- \* Mercurex
- \* Iodox
- \* Electrolytic Scrubbing
- \* Fluorocarbon Adsorption
- \* Other Solvents Absorption
- \* Comparison of Scrubbing Processes
- \* Solid Adsorbents
- \* Silver Nitrate on Substrates
- \* Silver Loaded Adsorbents
- \* Other Metal-loaded Adsorbents
- \* Activated Carbon
- \* Other Solid Sorbents
- \* Comparison of Solid Sorbents
- \* Other Technology
- 2.4.4.3 Processes for Removal of Iodine from Liquid

#### Streams

- 2.4.4.4 Immobilisation Forms
- \* Criteria
- \* Simple Iodine Compounds
- \* Iodine on Solid Sorbents
- \* Sodite
- \* Concrete
- \* Glasses
- \* Polymers and Organic Compounds
- \* Comparison of Immobilisation Forms
- 2.4.5 Disposal Options and Associated Radiological Impact
- 2.4.5.1 General Considerations
- \* Economic
- \* Environmental
- \* Socio-political
- 2.4.5.2 Dispersion and Transfer to the

Biosphere

# 2.4.5.3 Disposal in Geological Formations and Ocean

## Disposal

- 2.4.5.4 Other Disposal Options
- \* Transmutation
- \* Extraterrestrial Disposal
- 2.4.5.5 Khlopin Institute Research on Iodine
- 2.4.6 References
- 2.5 Tritium
- 2.5.1 Physical, Chemical and radiological Characteristics of Tritium
- 2.5.2 Tritium in Nature
- 2.5.3 Tritium in the Nuclear Fuel Cycle
- 2.5.4 Tritium Control Technology
- 2.5.4.1 Head-end Processing
- \* Voloxidation
- 2.5.4.2 Non-Head-end Processing
- \* Direct Storage
- \* Recycle within the FRP
- \* Isotopic Enrichment Process
- \* Distillation Electrolysis
- \* Vapour Phase Catalytic Exchange
- \* Liquid Phase Catalytic Exchange
- \* Combined Electrolysis and Catalytic Exchange
- 2.5.5 Conditioning Methods
- 2.5.5.1 Conditioning of Low-Level Tritium Bearing

# Aqueous Wastes

- \* Water: Element Ratio HTO
- \* Additives
- \* Cement Coating
- \* Immobilisation in Polymer-infraregulated Cement
- 2.5.6 Conditioning of Concentrated Tritium
- 2.5.6.1 Potential Storage methods
- \* Packaging as a Gas
- \* Packaging as Metal Hydrides
- \* Tritiated Organic Compound
- \* Other Packaging Methods
- 2.5.6.2 Immobilisation of Tritium as Metal Tritides
- 2.5.6.3 Packaging as Metal Tritides
- 2.5.7 References
- 2.6 Noble Gases in NPP's
- 2.6.1 Introduction
- 2.6.2 Noble Gas Delay Adsorbents
- 2.6.3 References
- 2.7 Noble Gases in Reprocessing
- 2.7.1 Characteristics and Arising of 85Kr
- 2.7.1.1 Radiological Impact
- 2.7.1.2 Disposal
- 2.7.2 Available Methods for the Separation of Krypton from

## Off-gases

- 2.7.2.1 Cryogenic Distillation Processes
- 2.7.2.2 Liquid Adsorption Processes
- 2.7.2.3 Selective Adsorption Processes
- 2.7.2.4 Special Processes
- 2.7.2.5 Separation of Krypton and Xenon
- 2.7.3 Removal of the Krypton from Reprocessing Off-gas
- 2.7.3.1 Industrial Sites

- \* (USA) Idaho Chemical Plant (Operating Plant)
- \* The AZUR Plant (FRG)
- 2.7.3.2 Experimental Plants
- \* The Japanese Krypton Pilot Plant
- \* Belgium, SCK/CEM Mol Plant
- \* The CEA Plant (France)
- \* The KRETA Plant (FRG)
- \* The CRYOSER Plant (FRG)
- \* Linde Cryogenic Plant (USA)
- \* Fluorocarbon Gas Liquid Adsorption Process Oak Ridge (USA)
- \* Single Column Fluorocarbon System (USA)
- \* Other Concepts
- 2.7.3.3 Off-gas Treatment for HTGR Reprocessing
- \* AKLU Process
- \* KALC Process
- 2.7.4 Conditioning Methods
- 2.7.4.1 Pressurised Containers
- 2.7.4.2 Adsorbent Fillings for Pressurised

#### Containers

- 2.7.4.3 Methods of Encapsulation
- \* Encapsulation in a Metal Matrix
- \* Encapsulation in Molecular Sieves
- \* Encapsulation in Foam Glass
- 2.7.4.4 Other Storage Methods
- 2.7.5 Engineered Storage
- 2.7.6 Transportation
- 2.7.7 Disposal
- 2.7.7.1 Disposal in Geological Formations and

# Grouted Hydrofracture

- 2.7.7.2 Sea Disposal
- 2.7.8 References
- 2.8 Carbon-14
- 2.8.1 Characteristics and arisings of Carbon-14
- 2.8.1.1 Properties
- 2.8.1.2 Radiological Impact
- 2.8.1.3 Occurrence
- \* In Nature
- \* As a Result of Reprocessing
- 2.8.2 Treatment and Conditioning of Carbon-14 in

# Nuclear Fuel Reprocessing

- 2.8.2.1 Off-gas Stream Characteristics
- 2.8.2.2 Aqueous Caustic Absorption Systems
- 2.8.2.3 The Fluorocarbon Absorption System
- 2.8.2.4 Solid Absorption Processes
- \* Combination of Ca(OH)2 and Ba(OH)2
- \* Barium Hydroxide
- 2.8.2.5 Adsorption Processes
- 2.8.3 References
- 2.9 Semi-volatile Radionuclides and Other Toxics
- 2.9.1 Introduction
- 2.9.2 Ruthenium Compounds
- 2.9.3 Cesium Compounds
- 2.9.4 Technetium Compounds
- 2.9.5 Other Semi-volatiles
- 2.9.6 References

- 2.10 Toxic Non-radioactive Compounds
- 2.10.1 Toxic Compounds Released External to the Facility
- 2.10.2 Toxic Compounds in the Process
- 2.10.3 Toxic Compounds in the Fuel

**Fabrication Process** 

2.10.4 Toxic Compounds in Spent Fuel

Reprocessing

- 3.0 Components and Elements of Air Cleaning and Gas Processing
- 3.1 Introduction
- 3.2 Fibrous Filters, Medium and High Efficiency
- 3.2.1 Introduction
- 3.2.2 Filter Types
- 3.2.2.1 Square Filters Deep Pleat
- 3.2.2.2 Square Filters Mini Pleat
- 3.2.2.3 Circular Filters Plug In
- 3.2.2.4 Circular Filters Push Through
- 3.2.2.5 Circular Filters Others
- 3.2.2.6 Metal Filters
- 3.2.3 Filter Construction
- 3.2.3.1 Filter Media
- 3.2.3.2 Filter Casings
- 3.2.3.3 Square Shaped Filters Deep Pleat
- 3.2.3.4 Square Shaped Filters Mini Pleat
- 3.2.3.5 Circular Filters Plug In
- 3.2.3.6 Circular Filters Plug In
- 3.2.3.7 Circular Filters Others
- 3.2.3.8 Metal Filters
- 3.2.4 Filter Housings
- 3.2.4.1 Single Square Open Frame
- 3.2.4.2 Multiple Square Open Frames or Ladder Rack
- 3.2.4.3 Bag Changed Single Square Filter
- 3.2.4.4 Bag Changed Multiple Square Filters
- 3.2.4.5 Bag Changed Single Circular Filter
- 3.2.4.6 Bag Changed Multiple Circular Filters
- 3.2.4.7 Bag Changed Push Through
- 3.2.4.8 Remote Change Filters
- 3.2.4.9 Non-Change Filters
- 3.2.5 Multistage Filtration
- 3.2.6 Changing Spent Filters
- 3.2.7 Spent Filter Disposal
- 3.2.8 Filtration Efficiency Testing and Performance
- 3.2.9 Operational Issues
- 3.2.9.1 Temperature
- 3.2.9.2 Differential Pressure
- 3.2.9.3 **Humidity**
- 3.2.9.4 Ageing of Filters
- 3.2.10 Medium Efficiency Fibrous Filters
- 3.2.10.1 Introduction
- 3.2.10.2 Prefilters
- 3.2.10.3 Supply Filters
- 3.2.10.4 Other Filters
- 3.2.11 New Technology
- 3.2.12 References
- 3.3 Granular Bed and Sand Filters
- 3.3.1 Introduction
- 3.3.2 The Evaluation of the Behaviour of

# Granulated Media Filters for Particular Removal

3.3.3 History of Deep Bed Filtration of

Particulate in the Nuclear Industry

- 3.3.4 References
- 3.4 Iodine Adsorbents
- 3.4.1 Introduction
- 3.4.2 Carbonaceous Adsorbents
- 3.4.3 Non-Carbonaceous Adsorbents
- 3.5 Modular Iodine Adsorbers
- 3.6 Monolithic Iodine Adsorbers
- 3.6.1 Introduction
- 3.6.2 References
- 3.7 Mist Eliminators, Coalescers, etc.
- 3.7.1 Introduction
- 3.7.2 Types of Mist Eliminators
- 3.7.2.1 Impaction Mist Eliminators
- 3.7.2.2 Diffusion Separators
- 3.7.3 Evaluation of Impact Eliminators
- 3.7.3.1 Monsanto Baffle-type Separator
- 3.7.3.2 Farr Type 68-44MZH Separator
- 3.7.3.3 York Type 321 SR Separator
- 3.7.3.4 AAF Type T Separator
- 3.7.3.5 MSA Type G Separator
- 3.7.3.6 ACS Model 101-55 Separator
- 3.7.4 Other Considerations
- 3.7.5 References
- 3.8 Scrubbers
- 3.8.1 Introduction
- 3.8.2 Chemical Scrubbers
- 3.8.3 Condensers
- 3.8.3.1 Direct Contact Condensers
- 3.8.3.2 Indirect Contact Condensers
- 3.8.4 Dust Scrubbers
- 3.8.5 Other Types of Scrubber
- 3.8.5.1 Submerged Bed Scrubbers
- 3.8.5.2 "Higee" Rotating Scrubbers
- 3.8.5.3 Vortex Scrubbers
- 3.8.6 New Technology
- 3.8.7 References
- 3.9 Cyclones
- 3.9.1 Introduction
- 3.9.2 Efficiency
- 3.9.3 Associated Mechanisms
- 3.9.4 Use in Shear/dissolver Off-gas
- 3.9.5 References
- 3.10 Recombiners (H2-O2) and (Nox-NH3)
- 3.10.1 H2 O2 Recombiners
- 3.10.2 NOx NH3 Recombiners
- 3.10.3 References
- 3.11 Other Considerations
- 3.11.1 Introduction
- 3.11.2 Additional Components
- 3.11.2.1 Fans
- 3.11.2.2 Instrumentation / Control
- 3.11.2.3 Lutes
- 3.11.2.4 Leakage

- 3.11.2.5 Stacks
- 3.11.2.6 Power Supplies
- 3.11.2.7 Failure
- 3.11.3 Additional Influences
- 3.11.3.1 Watering Systems
- 3.12 System Testing
- 3.12.1 Introduction
- 3.12.2 Test Conditions
- 3.12.3 Components to Test
- 3.12.4 Other Considerations
- 3.12.5 References
- 3.13 New Technologies
- 3.13.1 Introduction
- 4.0 Nuclear Power Plant and Research Reactors.
- 4.1 Introduction
- 4.2 Ventilation Systems
- 4.2.1 System Design
- 4.2.1.1 Design Criteria
- 4.2.1.2 Normal Ventilation Systems
- 4.2.1.3 Exhaust Air Treatment Systems
- 4.2.1.4 Make-up and Intake Air Filtering Systems
- 4.2.1.5 Air Handling Units
- 4.2.1.6 Housings (filter)
- \* Integral Filters and Housings
- 4.2.1.8 Prefilters
- 4.2.1.9 Moisture separators
- 4.2.1.10 Heaters & Heater Controls
- 4.2.1.11 HEPA Filters
- 4.2.1.12 Charcoal Adsorbers, Types II, III & IV
- 4.2.1.13 Dampers
- 4.2.1.14 Fans and Motors
- 4.2.1.15 Heating and Cooling Coils
- 4.2.1.16 Ductwork
- \* Structural Design
- 4.2.1.17 Paints and Protective Coatings
- 4.2.1.18 Hangers, Supports, and Anchors
- 4.2.1.19 Air Intakes and Air Discharge Stacks
- \* Locating Air Intakes and Air Discharge Stacks
- \* Sizing Intakes and Stacks
- \* Structural Design Aspects
- 4.2.2 Operating Experience
- 4.2.3 Testing and Maintenance
- 4.2.3.1 Air Cleaning System Design
- 4.2.3.2 Design Item Checklist
- 4.2.3.3 Arrangement & Size Of Housings And

# Component Banks

- 4.2.3.4 Testing Air Cleaning Components And Systems
- 4.2.3.5 In-Place Component Tests And Criteria
- 4.2.4 Heavy Water Reactors
- 4.2.4.1 Introduction
- 4.2.4.2 Sources Of Liquid Radioactivity
- 4.2.4.3 Tritium
- \* Other Radionuclides
- 4.2.4.4 Radioactive Effluents From Candu 6 Reactors
- 4.2.5 High Capacity Channel Reactor (RBMK)
- 4.2.6 References

- 4.3 Noble Gas Control in NPP's
- 4.3.1 Noble Gas Control in PWRs and WWERs.
- 4.3.1.1 Source Term for PWR Gas Processing Systems.
- 4.3.1.2 PWR and WWER Gaseous rad waste systems.
- 4.3.2 Noble Gas Control in BWRs
- 4.3.2.1 Source Term for BWR Off-gas Systems.
- 4.3.2.2 BWR Off Gas Systems.

Possible information and sections; 4.3-3 WWER's

- 4.3-4 Gas Cooled Reactors
- 4.3-5 LMFBR
- 4.3.6 References.
- 4.4 Special Issues
- 4.4.1 Control Room Habitability
- \* Normal Operation
- \* Accident Conditions
- \* Ventilation System Requirements
- 4.4.2 Fire Protection
- 4.4.3 References
- 5.0 Fuel Fabrication Facilities
- 5.1 Introduction
- 5.2 Uranium Oxide Fuel Facilities
- 5.2.1 Introduction
- 5.2.2 Production Plants
- 5.2.2.1 Hematite Facility
- 5.2.2.2 Oxide Plant
- 5.2.2.3 Powder Preparation and Blending
- 5.2.2.4 Pellet Production
- 5.2.2.5 Other Processes
- 5.2.2.6 Chemicals and Discharges
- 5.2.3 Columbia Facility
- 5.2.3.1 Introduction
- 5.2.3.2 UF6 Conversion to Oxide
- 5.2.3.3 Powder Preparation and Blending
- 5.2.3.4 Sintering and Grinding
- 5.2.3.5 Other Processes
- 5.2.3.6 Chemicals and Discharges
- 5.2.4 Springfields Facility
- 5.2.4.1 Typical Process and System Design
- 5.2.4.2 Challenges to the Off-gas System
- 5.2.4.3 Operating Experiences
- 5.2.4.4 Discharges and Regulatory Issues
- 5.3 Mixed Oxide Fuel Facilities
- 5.3.1 Introduction
- 5.3.2 Typical Plutonium Finishing Process
- 5.3.3 Typical MOX Fuel Production Process and System

## Design

- 5.3.4 Challenges to the Off-gas System
- 5.3.5 Operating Experiences
- 5.3.6 Discharges and Regulatory Issues
- 5.4 Metal Fuel Facilities
- 5.4.1 Introduction
- 5.4.2 Typical Process and System Design
- 5.4.3 Challenges to the Off-gas System
- 5.4.4 Rod Fabrication
- 5.4.5 Canning
- 5.4.6 Operating Experiences

- 5.4.7 Discharges and Regulatory Issues
- 5.5 Research Fuel Types
- 5.5.1 Introduction
- 5.5.2 Alteration/Enrichment of Existing Uranium Fuel Types
- 5.5.3 Alteration/Enrichment of Existing Metal Fuel Types
- 5.5.4 New Fuel Compounds
- 5.5.5 Challenges to the Off-gas System
- 5.6 References
- 6.0 Fuel Reprocessing Facilities
- 6.1 Introduction
- 6.2 Spent Fuel Characteristics
- 6.3 Shearing / Dissolution of Spent Fuel
- 6.3.1 Shearing of Spent Fuel
- 6.3.2 Dissolution of Spent Fuel
- 6.4 Off-gas Characteristics
- 6.4.1 General Characteristics
- 6.4.2 Aerosols
- 6.4.3 Radionuclides
- 6.4.3.1 Tritium
- 6.4.3.2 Carbon
- 6.4.3.3 Krypton and Xenon
- 6.4.3.4 Iodine
- 6.4.4 Non-Radioactive Chemicals
- 6.5 Typical Off-gas Systems
- 6.5.1 Basic Off-gas Systems in Reprocessing Facilities
- 6.5.2 Off-gas Systems in UK Reprocessing Facilities
- 6.5.2.1 Magnox Reprocessing
- 6.5.2.2 Thermal Oxide Reprocessing in THORP
- 6.5.2.3 Fluidic Devices in THORP
- \* Aerosols from Liquor Movement
- \* Pulsed Columns
- 6.5.3 Off-gas Systems in French Facilities
- 6.5.3.1 UP3 Reprocessing Facility
- 6.5.3.2 Japanese Reprocessing Plants
- 6.5.4 Off-gas Systems in Russian Facilities
- 6.5.5 Off-gas Systems in Other Facilities
- 6.5.5.1 Hanford Purex Plant
- 6.5.5.2 Eurochemic Facility at Mol, Belgium
- 6.5.5.3 West Valley Plant, USA
- 6.5.5.4 Barnwell Plant, USA
- 6.5.5.5 Exxon Plant, Morris, Illinois, USA
- 6.5.5.6 WAK Plant, Karlsruhe, Germany
- 6.5.5.7 German 'MILLI' Scheme
- 6.6 Pyrochemical and Pyrometallurgical Reprocessing Facilities
- 6.6.1 Pyrochemical Reprocessing
- 6.6.2 High carbon Fuels
- 6.6.3 'DRY' Methods of Reprocessing
- 6.7 New Research in Reprocessing Facilities
- 6.7.1 New Fuel Cycle
- 6.8 References
- 7.0 Waste Processing Facilities
- 7.1 Introduction
- 7.2 Ambient Temperature Processes
- 7.2.1 Introduction
- 7.2.2 Low-level Waste Compaction and

Cementation

7.2.3 Intermediate Level Waste Treatment /

Cementation

7.2.4 Plutonium Contaminated Waste

Treatment / Cementation

7.2.5 Temporary Decommissioning Facilities

7.2.6 References

7.3 Elevated Temperature Processes

7.3.1 Vitrification

7.3.1.1 General Aspects of Cleaning Off-gas

from Vitrification

Processes

7.3.1.2 AVM Plant (France)

7.3.1.3 SIA "RADON" (Russia)

7.3.1.4 "MAYAK" PA (Ozyorsk, Russia)

7.3.1.5 West Valley USA

7.3.1.6 The DWPF Savannah River System

7.3.1.7 Pacific Northwest Laboratories

(Richland, WA)

7.3.1.8 PAMELA Plant (Federal Republic of

Germany)

7.3.1.9 The Hanford LAW and HLW

Vitrification Plant Design

7.3.1.10 Other Facilities

7.3.2 Incineration

7.3.2.1 Introduction

7.3.2.2 Waste Characteristics

7.3.2.3 Incinerator Types and Off-gas

Compositions

\* Moscow SIA RADON

\* Forschungszentrum KARLSRUHE (FZK)

\* STUDSVIK the THORSM Process

\* Thermal Treatment of Solid Waste in a Plasma Furnace

\* Secondary Waste Treatment

7.3.2.4 General Descriptions of Technologies

for Off-gas Treatment

\* Dry Off-gas Treatment

\* Wet Off-gas Treatment

\* Combined wet and Dry Cleaning Systems

\* Gas Handling System for the ThorSM System

7.3.2.5 General Design Features

\* The Type of Afterburner

\* Hot Gas Filters

\* Cooling

\* Flue Gas Scrubbing System

\* Fine Filters

\* Catalytic Reactor and MSW Filter

7.3.2.6 Environmental and Regulatory

Considerations

\* Chemical Discharges under Normal Conditions

\* Critical Safety

7.3.3 References